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Hybrid PON-FSO based fronthaul architecture for ultra-dense small cell network

Syed Saeed Jaffar[a,*], **Ashiq Hussain**[a], **Paulo Valente Klaine**[b], **Muhammad Zeeshan Shakir**[c], **Muhammad Ali Qureshi**[d]
[a]Hitech University, Electrical Engineering Department, Taxila, Pakistan
[b]University Of Glasgow, United Kingdom
[c]University of the West of Scotland, School of Engineering and Computing, , Paisley, Scotland, UK
[d]Telecommunication Engineering Department, The Islamia University of Bahawalpur, Pakistan

Abstract. In future Radio Access Network (RAN), many small cells will be densely deployed to meet the capacity demand of mobile users. Centralized Radio Access Network (CRAN) is a potential solution to increase the capacity demand of RAN. CRAN breaks the functionality of RAN between Remote Radio Head (RRH) and Base Band Unit (BBU) where RRH and BBU are preferably connected by an optical link called fronthaul link. However, the deployment of fiber for fronthaul connectivity, at each Small Cell (SC) location, is impossible or impractical due to cost or other constraints. As such, Passive Optical Network (PON) and Free Space Optic (FSO) technologies have emerged as potential candidates for fronthaul transmission when the complete optical fiber-based infrastructure for fronthaul network cannot be deployed alone. In this paper, we propose a hybrid PON and FSO based method for SC fronthaul connections that considers three different network constraints i.e. bandwidth, data rate, and latency. Based on this, we formulate the problem and propose a novel method to perform cell association, namely Minimum Sum Selection (MSS). The performance is evaluated in terms of the number of SCs connected and the proposed method is compared with two other baselines, namely: Minimum Rate Selection (MRS) and Random Selection Method (RSM). The results show that despite MSS requiring knowledge of all network constraints, it has a better performance at the cost of more computation resources, achieving gains of 7% and 6.5% in cell connections when compared to the other two baseline methods.

Keywords: Centralized Radio Access Network (CRAN), Passive Optical Network (PON), Front Haul (FH), Free Space Optics (FSO), NGPON2, Fifth generation (5G)..

*Syed Saeed Jaffar, saeed.jaffar@gmail.com

1 Introduction

1.1 Background

Mobile traffic is increasing day by day and this trend is expected to be continued for many years in the future.[1] This expected growth continues in terms of both numbers of connected devices and new services. Some causes of the increase in network traffic include machine-to-machine communication, tactile internet, online gaming, and social networking sites. Such huge bandwidth demands cannot be fulfilled by existing cellular networks, thus, causing the demands of next-generation technology in the wireless world i.e. Fifth Generation (5G).[2] In 5G, many Small Cells

(SCs) will be densely deployed and some requirements of 5G network are discussed in.[3–5] To meet these demands, network operators require cost and energy-efficient deployment strategies.

Therefore, to satisfy network/users requirement and at the same time to align revenue growth of telecommunication operators, academia and industry have explored evolution in radio network deployment strategy i.e. Centralized Radio Access Network (CRAN).[6–10] CRAN is a novel radio network architecture that reduces both the capital and operational cost of a network at almost 50% as reported by different network operators such as Nokia, Siemens, and Intel.[11,12] In CRAN, the functionality of the base station is split into two parts, i.e. Radio Remote Head (RRH) and Base Band Unit (BBU) where RRH and antenna remain at the cell site and the BBU moves from cell site to central office or an aggregation point. Multiple RRH's need to be connected to the BBU with a high-speed transport network called the fronthaul interface, which requires data rate up to gigabit level.[13] Therefore, the radio network evolution requires the integration of high speed, flexible, and cost-effective fronthaul transport networks.

There exist multiple gigabit-capable technologies that can support fronthaul transport networks such as Passive Optical Network (PON), Free Space Optic (FSO), and millimeter waves are striking options.[14–18] In this paper, we target both optical-based technologies i.e. PON and FSO for fronthaul connections. This leads to significant economies of scale in the design of the fronthaul network. PON is point-to-multipoint passive optical technology and is gradually replacing the copper-based network from the access end.[2] PON comprises three layers, i.e. Optical Line Terminal (OLT), Optical Network Unit (ONU), and Optical Distribution Network (ODN). The OLT is placed at an operator central building while the ONU is placed near customer locations. One OLT can connect multiple ONUs through ODN and a passive splitter as shown in Fig. 1. PON was created by the Full-Service Access Network (FSAN) in the 90's and since then Institute of

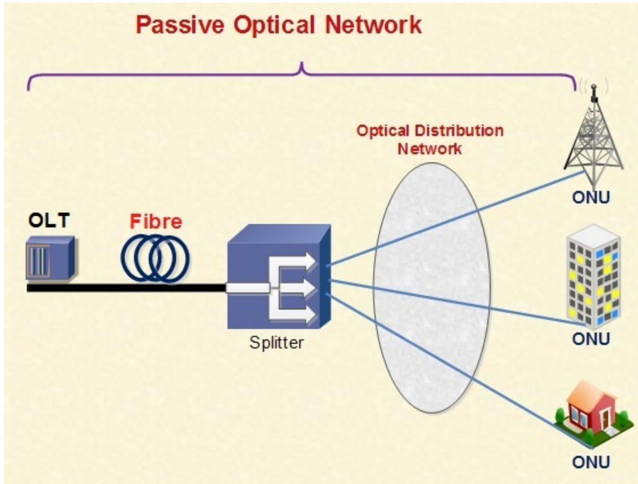

Fig 1: A typical architecture of passive optical network.

Electrical & Electronics Engineering (IEEE) and International Telecommunication Union (ITU) have standardized PON technologies.[19–21] There are four main PON standards and are classified into two main groups. The first class of PON architecture is called Asynchronous Transfer Mode (ATM) and includes ATMPON, Broadband PON (BPON), and Gigabit PON (GPON). The second architecture is called Ethernet PON (EPON).[21,22] Nowadays, EPON is mostly deployed in Asia, while GPON is deployed in other regions. Technologies beyond GPON are called next-generation PON that have been standardized by ITU-T.[2] At the moment, ITU standardized Next Generation Passive Optical Network (NGPON2) for implementing next-generation PON technology and it can provide gigabit bandwidth connection, with low cost, to fronthaul network.[23,24]

The basic requirements of NGPON2 is summarized by ITU[25] and FSAN.[26] The NGPON2 evolved in the most valuable optical fiber band, the C band, and L+ band.[27] Depending on the technical solution for the laser control for Time Wavelength Divisional Multiplexing (TWDM) (NGPON2), the 100 GHz grid may be too tight for the receiver discrimination filter at the ONU, and the 1000 GHz could be too coarse for the optimum band usage.

On the other hand, FSO is also gaining popularity as a cost-effective and high bandwidth technology that can offer bandwidth up to 1.2 Tbps over 1 km distance.[28] However, the capacity of FSO is affected by weather turbulences.[29] The 1550 nm wavelength is best for both rain and haze as there is less attenuation than any other wavelength. The FSO link performance can be determined by several parameters such as data rate, power link range, number of users, and channel spacing. In critical weather conditions, short link distance and lower data rates can be used to optimize the FSO system for successful transmission.[30] Furthermore, the study[31] summarizes the work based on different parameters like wavelength, power level, data rate, and link distance with different techniques to analyze the performance of FSO link.

Additionally FSO link performance can also be degraded due to integration with WDM or PON signal. The FSO system currently offers a much lower capacity than the current fiber communication systems and typically showed error bursts in long-time operation, resulting in a high average Bit Error Ratio (BER). The highest presented results on FSO transmission 16×10 Gb/s in a terrestrial link,[32] and 2×40 Gb/s system working over an aerial link. Both systems were one-way and suffered from sudden system outage (means BER higher than 10^{-8}). The authors in[33] demonstrated the outdoor field trials that FSO links can be used to achieve high reliability against weather and misalignment conditions and limited data rate degradation for relatively low distances i.e. up to 100 m.

Optical fiber due to its low loss, reliability, and high data rates is the most suitable solution for fronthaul network, however, in some situations, fiber installation is not alone appropriate solution for instance in difficult terrain, a short-lived event such as in the stadium or disaster management, etc.[34,35] In these cases, FSO provides ease of setup, tear down, and provides alternative to fiber. As compared to Radio Frequency (RF) communication, FSO has the advantages of higher capacity, cost-effectiveness, immunity to electromagnetic interference, and licensed-free bandwidth.[36,37] On

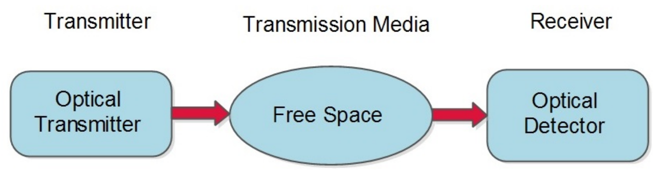

Fig 2: Basic architecture of free space optic network.

the other hand, FSO has some limitations such as atmospheric attenuation and turbulence-induced scintillation.[38–41] In these situations, Integrated PON and FSO are the best solutions for fronthaul sections of 5G as both systems share the same transmission wavelength and system components to transfer data.[42–45] We use the idea of employing a macro cell as fronthaul hub and present an efficient algorithm for the association of macro cell and distributed RRH. The basic structure of FSO is shown in Fig. 2.

1.2 Related Work

The 5G mobile network can support the massive deployment of SCs. This approach can be efficiently handled by CRAN. However, CRAN put stringent requirements on the transport section i.e. on the fronthaul network. Therefore, various researchers worked on this field.[2] The idea of addressing the fronthaul service through PON solution such as Wavelength Division Multiplexing (WDM) PON and Ultra-Dense (UD) WDM-PON is presented in.[46] Another idea of using hybrid technology of PON i.e. Time Wavelength Division Multiplexing (TWDM) PON with FSO technology is presented in.[18] To solve the fronthaul operational and capital expenditure, Waqar et al.[47] use a PON-based link for long distances by adding the Erbium-Doped Fiber Amplifier(EDFA). By adding the EDFA link, the limitation of fronthaul improves but it simultaneously increases the cost of fronthaul network. Similarly, Larsen et al.[48] reviewed different functional split options to reduce the data rate requirement on the fronthaul network. Studied shows that a high-level functional split option can reduce the data rate requirement on the fronthaul network and therefore this option can increase the link length of the fronthaul network. On the other hand, a low-level split option can support low distance due to high data rate requirements. But both methods have their pros and cons as discussed in.[2] Shibata et al.[49] deployed the Time Division Multiplexing Passive Optical Network (TDM-PON) method and used the compression techniques to reduce the data rate requirements on fronthaul and simultaneously increase the transmission distance of the fronthaul network. Waqar et al.[50] discussed the pros and cons of different fronthaul transport technologies in detail concerning distance, cost, and performance measurement. Wan et al.[51] proposed a software-defined network for PON based fronthaul network for achieving different data rates and cost benefits.

Generally, the fronthaul network is realized by different technologies such as optical fiber and wireless fronthaul.[11] Therefore researchers also worked on optical wireless communication technology and considered it as an alternative or complementary solution to RF wireless technology.[52–55] The issue to provide service in those areas where high bandwidth is required cost-effectively and where optical fiber cannot be easily deployed, the researchers considered WDM and FSO technology as a promising solution.[18] Ciaramella et al.[56] worked up to 1.28 Tbps WDM transmission and demonstrated that FSO with WDM technology is suitable for high quality as well as for high bandwidth application services.

In the literature, different techniques are discussed for the integration of PON and FSO which are summarized in.[57–59] To provide flexible and high-speed connectivity of optical fiber with the free-space optical communications, a new compact laser communication terminal has been developed at the National Institute of Information Communication Technology Tokyo, Japan. The terminal has a feature to connect the free-space laser beam directly to single-mode fiber by using a special fiber coupler to focus the free-space laser beam and couple it into the single-mode fiber. Furthermore, it is also reported that FSO transmission systems are fully compatible with optical fiber communication networks, especially with PONs.[18] Thanks to the development of FSO terminals which can be transparently connected to single-mode fibers.[60]

In our proposed hybrid system approach, FSO and optical fiber links (based on TWDMPON), share the identical transmission wavelengths (1550 nm) and system components. The use of TWDM-PON enables the system for long-range and extended capacity while the use of FSO technology offers flexibility and cost-effectiveness. The NGPON2 (TWDM PON) system manages efficiently the varied traffic demands from the end-user. In the literature, researchers discussed various bandwidth allocation algorithms for NGPON2 such as the conventional DBA algorithm[61] that includes a fixed window algorithm that allocates a fixed transmission window (bandwidth) regardless of a user traffic condition, a gated window algorithm in which the OLT allocates a requested bandwidth if the ONU calculates the amount of the traffic of the end-users queuing at the ONU and requests the corresponding bandwidth allocation. A credit window algorithm is used in which the OLT allocates the extra bandwidth to ONU'S. A wavelength and bandwidth allocation algorithm for TWDM-PON for variable mobile fronthaul traffic via the dynamic wavelength and bandwidth allocation (DWBA) scheme was also proposed.[61,62]

Through literature, we have observed the biggest obstacle in CRAN implementation is the requirement of huge capacity and cost-efficient fronthaul link i.e. efficient front hauling remains a significant challenge in CRAN deployment. Among practical transmission media, optical fiber has been the obvious choice for fronthaul links mainly due to its large bandwidth capabilities.[11,63] However, implementation and maintenance of optical fiber systems are costly and it is not always possible to deploy fiber in any environment. The FSO has emerged as a potential candidate technology for last-mile access for many applications. It provides the same bandwidth over the short-range as the optical fiber system does. FSO is also cost-efficient, flexible, and easy to upgrade technology. The hybrid approach of PON-FSO has emerged future direction of research for C-RAN front haul application as both technologies provide a cost-efficient solution to the network operator to built the fronthaul network, especially in hard reach areas.

In order to implement the above-mentioned challenges, the main contributions of our work are as follows:

1. We considered the use of a novel hybrid PON-FSO based fronthaul architecture to provide fronthaul connectivity to ultra-dense small cell networks. As totally fiber or deep fiber-based architecture for fronthaul applications is not a cost-effective/feasible solution and it is impossible to deploy fiber especially in densely populated urban areas.

2. We formulated the association problem of macro base stations with SCs considering many parameters of macro cell link such as bandwidth, data rate, latency, and a number of supported links. These are the major design concerned in the cell association process. We present an efficient solution to these problems to maximize the sum rate of overall network metrics.

3. We proposed novel methods for the SCs association, namely: Minimum Sum Selection (MSS), and evaluate its performance using Monte Carlo simulations. The proposed method is compared to the Baseline of Random Selection Method (RSM) and Minimum Rate Selection (MRS).

The remainder of this paper is organized as follows. Section 2 presents the system model of the proposed hybrid PON and FSO framework. Section 3 formulates the problem, while Section

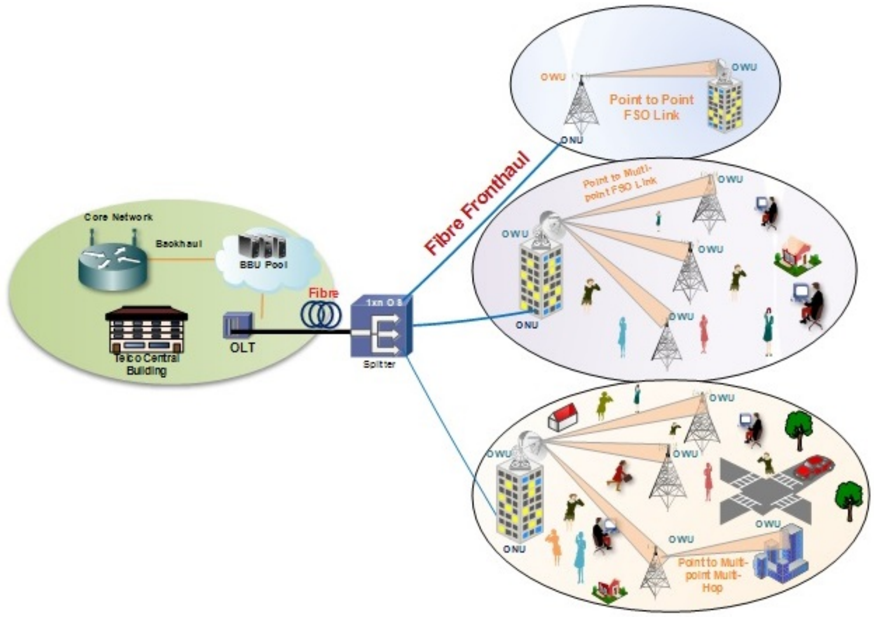

Fig 3: Proposed hybrid PON & FSO network for fronthaul architecture.

4 presents the proposed solution. Results are discussed in Section 5 and conclusions are drawn in Section 6.

2 System Model

In this work, a heterogeneous network is considered which is composed of a macro cell and multiple SCs. A macro cell is randomly distributed in an area of 1000 m^2 according to a Matern Type-I hardcore process.[55] In addition, a set of SCs, $S = \{s_1, s_2, s_3, \cdots, s_n\}$ are also distributed, within the coverage of macro base station, following a Matern Type-I hardcore process. An example of network stochastic geometry is shown in Fig. 5. In CRAN architecture, fronthaul traffic of each SC is processed in the cloud so each SC can be communicated with one or many macro cells for fronthaul connection. The combined fronthaul architecture of both technologies is presented in Fig. 3.

In the proposed model, the SCs can be connected directly to the macro cell, i.e. Point-to-Point (PtP) FSO link or indirectly point-to-multipoint multi-hop fashion as shown in Fig. 3. In both

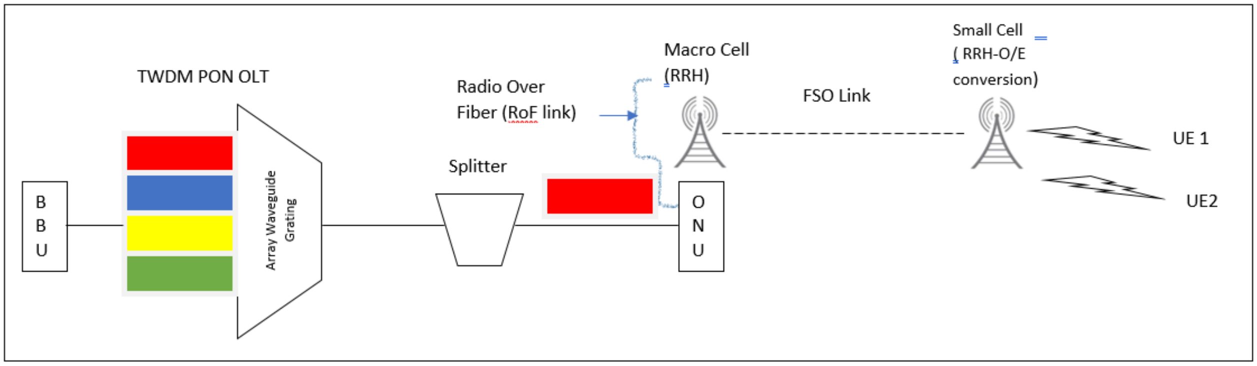

Fig 4: Illustration of FSO and RRH unit at Small Cell.

cases, the latency (L) of the link is dependent upon the line of sight propagation delay, which is a function of distance over the speed at which the signal propagates, i.e. distance of the small cell form macro cell divided by the speed of light. The distance (d) between macro cell and small cell can be calculated as follows

$$d = \sqrt{(x - x_0)^2 + (y - y_0)^2}, \tag{1}$$

where x and y are the positions of macro cell along the x-axis and y-axis respectively, x_0 and y_0 are the the position of SC along the x-axis and y-axis respectively. While the latency, is expressed as

$$L = \frac{C}{d} \tag{2}$$

where L is latency, C is speed of light, d is distance between macro cell and SC.

We have proposed at every SC an FSO link and RRH unit as shown in Figure 4. At each SC we convert optical signal into electrical signal through RRH. The RRH unit which are distributed across cell sites provide wireless signal coverage to User Equipment (UE). Each RRH is also connected to BBU (through PON and FSO). The RRH passes quantized samples of analog wireless signals via the Common Public Radio Interface (CPRI) to the BBUs for further processing. Whereas the physical location of BBUs can be in a Central Office (CO) that stretches tens of kilometers from the RRH's but is connected through a reliable optical network, namely, the fronthaul.

All signal processing such as wavelength management, and modulation are performed at the BBU. The role of RRH is simply to convert the optical signal to electrical form and vice versa and perform amplification and transmission of the wireless signal at a designated frequency and thus making the RRH simple and inexpensive[2,64] or we can say that in the proposed architecture, RF signals are generated at the RRH by using all-optical processing. RRHs can be equipped with FSO devices easily and thus simplifying the network deployment.[65]

It is also mentioned in Fig. 4, the RRH of SCs communicated to macro cell through the FSO link. In this work, we use the FSO link as an extension of optical fiber in the proposed fronthaul segment with a very short FSO link length with a wavelength of 1550 nm. The use of 1550 nm operating wavelength for the FSO link is also compatible with most commercial FSO systems. At this wavelength, the FSO links can be longer and better able to operate in unfavorable meteorological conditions, e.g., fog and it is also suitable for EDFA and high-quality transceivers.[66,67] In the proposed work we have adapted ground to ground free space communication for the typical link range of up to 1 km which can be expressed as $h = h_l h_p h_a$, where h_l is the path loss (static link distance), h_p denoting the pointing error, and h_a representing the turbulence fading. We have assumed the atmospheric turbulence loss (cloud, rain, smoke, gases, temperature variations, fog, and aerosol) i.e. free space attenuation up to 10 db/km (in a moderate situation) as a system parameter during a simulation. However, the primary motivation for our research is to study the association of SCs with macro cell considering several parameters such as bandwidth, data rate, latency, and number of supported links.

Moreover, macro cell aggregates, fronthaul traffic of RRH's, and multiplexer on a single shared fiber infrastructure through (TWDM-PON). The components that are used in the integration of PON and FSO are OLT and ONU.[68] TWDM-PON OLT provides a multi-service platform that serves mobile fronthaul/backhaul services, business, residential, Machine to Machine (M2M), and Internet of Things (IoT) services. Each TWDM port will serve 64 clients (Residential, fixed broadband or MFH/MBH) with an aggregated bandwidth of 10 Gb/s (maximum on single downlink wavelength).

In the proposed solution we have considered only the MFH users (with variable data rate which can be requested by different small cells in the area of 1 km). Our PON system is deployed in brownfield scenario where broadband services through PON are already deployed. When the demand for high data rate in the region where the PON is installed is predicted high, (more heavy users, business and MBH), the number of TWDM ports should be kept low, allowing a moderate number of users and the average data rate is higher than 600Mb/s. If the region is an area where the majority of the clients are moderate to light users, then the number of ports of TWDM is higher with the average data rate up to 280 Mb/s.

Another reason not to use (Tb/s data rate in our system) is the accounting for Optical Path Penalties (OPP) in an optical-based system. For NGPON2 we have to consider some physical parameters of fiber in the system such as chromatic-dispersion-related penalties (When using 10 Gb/s in the C/L-band, and just 20 km of fiber) some form of dispersion compensation is necessary to achieve the OPP values in G.989.2. This can increase the cost of the fronthaul network. Apart from this the relatively high optical power and multi-wavelength usage in NGPON2 causes another degradation in the system called Raman nonlinearity. This can result in nonlinear cross-talk and signal depletion for certain wavelengths.

3 Problem Formulation

We formulate the association problem of macro base stations with SCs considering several parameters of macro cell as discussed above such as bandwidth, data rate, latency, and a number of supported links. These are the major design concerns in the cell association process. We present an efficient solution of these problems in order to maximize the sum rate of overall network metrics.

Therefore, our objective is to find out how many SCs can be efficiently associated with single macro cell in order to get the front haul connection. In the optimization problem, we incorporated number of constraints including maximum number of links that macro cell and every SC can support also denoted by Z and z respectively, maximum bandwidth (B) supported by macro cell, maximum data rate (R) and latency limit (L). Moreover, cell association also depends upon SC requires bandwidth (b), data rate (r), and latency (l). Macro cell will give priority to SCs whose requirements are less or equal than the total planned capacity of macro cell. If the requirements cannot be satisfied by macro cells the SCs will be disassociated from the network. The decision making process of SCs association with macro cell can be formulated as follows:

$$\underset{B,R,L,Z}{\text{maximize}} \sum_{i=1}^{N_m} \sum_{j=1}^{N_{SC}} A_{i,j}, \tag{3a}$$

$$\text{subject to} \sum_{i=1}^{N_m} \sum_{j=1}^{N_{SC}} A_{i,j}.b_{i,j} \leq B_i, \tag{3b}$$

$$\sum_{i=1}^{N_m} \sum_{j=1}^{N_{SC}} A_{i,j}.r_{i,j} \leq R_i, \tag{3c}$$

$$\sum_{i=1}^{N_m} \sum_{j=1}^{N_{SC}} A_{i,j}.l_{i,j} + L_i \leq L_{T\alpha}, \tag{3d}$$

$$\sum_{i=1}^{N_m} \sum_{j=1}^{N_{SC}} A_{i,j} \leq Z. \tag{3e}$$

From the optimization problem shown in Eq. 3a, it can be seen it is subject to four different constraints. Constraint (Eq. 3b) specifies that the total bandwidth ($\sum\sum A_{ij}\, b_{ij}$) of all small cells connected to the macro cell should not exceed the total bandwidth of the macro cell (B). Besides, constraints (Eq. 3c) states that the total data rate of all SCs connected to the macro cell should not exceed the total data rate of the macro cell (R). Constraint (Eq. 3d) states that the latency between the connected SCs, either by single- hop (l_{ij}) or multi-hop (L_i) should not exceed a threshold (L_{Tot}). We assume that the macro cell has a fixed latency to the core network, of 20 ms (given by L_i). All other small cells that connect to the macro cell, have a latency dependent on the distance between them and the number of hops (which can be more than one). Thus, if a small cell is able to connect to the macro cell, either directly or by multi hops, $A_{i,j}$ will be 1, otherwise it will be set to 0. In the event that no small cells are able to connect to the macro cell, only the fixed latency between the macro cell and the core network is considered. Moreover, constraint (Eq: 3e) refers that the total SCs connected to the macro cell should not exceed the total link support of the macro cell (Z).

Actually the proposed fronthaul system is designed with NGPON2 and FSO. We can transmit up to certain data rate on PON link (say 10 Gb/s on a single wavelength for downlink channel). But when we consider FSO its transmission characteristics depends upon many factors such as distance, environment and the link type (point to point link, point to multipoint).

Therefore, we have considered in the simulation all these constraints i.e. bandwidth, data rate, latency, and a number of supported links that can support macro cell/aggregation point. In the simulation, we have considered the area of 1 km maximum (macro cell and SCs are randomly distributed in the average area capacity of 1 km according to a Matern Type-I hardcore process). In a practical scenario, we have multiple macro cells for the coverage of another specified region (we have numbers of SCs in these areas). So all these macro cells/SCs will get fronthaul connectivity from the same PON (as shown in Fig. 3).

4 Proposed Solution

We propose a novel method for the SCs association problem, namely MSS and evaluate its performance using Monte Carlo simulations. The proposed method is compared to the baseline of RSM and MRS. In MSS method, we select SCs according to the sum of all requirements (bandwidth, data rate, and latency), in ascending order. Such that:

$$s_1 < s_2 < s_3 < \cdots < s_{N_{SC}}, \text{ where } s = b + r + l \tag{4}$$

In RSM, the SC requirements are chosen randomly between either bandwidth, data rate or latency, and later sorted in ascending order. Such that:

$$x_1 < x_2 < x_3 < \cdots < x_{N_{SC}} \tag{5}$$

where x is randomly chosen between bandwidth, data rate or latency. Lastly, MRS select SCs according to its data rate demand (in ascending order). Such that:

$$r_1 < r_2 < r_3 < \cdots < r_{N_{SC}} \tag{6}$$

where r is the data rate of the small cells.

Based on these three methods, the performance of the proposed solution, MSS, is evaluated and compared to the other two baselines for a varying number of small cells. Furthermore, the impact that each SC requirement (bandwidth, data rate, and latency) has on the fronthaul connectivity is also investigated. Results are generated by averaging a total of 100 Monte Carlo simulations.

In addition, the macro cell can only support a fixed number of links, given by Z. Each SC also has a limited number of connections it can support. In this case, each SC can have at most 2 connections. In our scenario, one macro cell is randomly deployed according to a Matern process. In the coverage area, number of SCs i.e. $N_{SC} = [12, 16, \cdots, 60]$ are deployed as shown in Fig. 5. The position of the SC is also random (Matern process). Each SC has random requirements in terms of bandwidth (b), data rate (r), and latency (l).

Algorithm 1: Hybrid PON and FSO based connection method for small cell fronthaul

Input: Macro and small cell positions, B, R, L, Z, b, r, l, z, A, and λ, α, β
Output: Allocated SC A_{ij}

for *each Monte Carle iteration* **do**
  for *each method* **do**
    reset SC count
    for *each SC in set* **do**
      for *all iterations* **do**
        Calculate position of macro cell
        Calculate positions of SC
        Calculate distance of SC from macro cell
        Calculate latency of each SC in a given set
        Select bandwidth for each SC
        Select data rate for each SC
        Calculate distances between SC
        if *method is MRS* **then**
          Sort the data rates (r) of SCs
        end
        if *method is RSM* **then**
          Sort randomly between bandwidth (b), data rate (r) and latency (l) of SCs
        end
        if *method is MSS* **then**
          Sort the sum of bandwidth (b), data rate (r) and latency (l) of SCs
        end
        for *all small cells* **do**
          Update association vector (A_{ij}) status with 0 or 1
        end
      end
    end
  end
  Return allocated SC A_{ij}
end
Calculate the average of SC connections

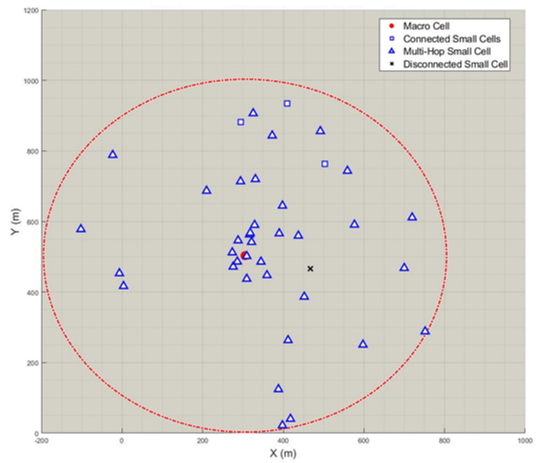

Fig 5: Network Geometry.

Table 1: Simulation parameters

Parameter	Value	
Number of macro cells	1	
Macro cell radius	500	m
Area	1	km
Number of SCs (N_{SC})	$12:04:60$	
Bandwidth of macro Cell (B)	$[1, 50, 100, 150, 200, 500]$	MHz
Data rates supported by macro cell (R)	$[0.1, 0.25, 0.5, 0.75, 1]$	Gbps
Latency limit of macro cell (L)	$[1, 5, 10, 15, 20, 50]$	μsec
Maximum number of links in macro cell (Z)	3	
Bandwidth of SCs (b)	$[1.4, 3, 5, 10, 20]$	MHz
Maximum number of links in SCs (z)	2	
Latency limit of SCs (l)	200	μsec

5 Results and Discussions

5.1 Metrics

Before the results for each method are presented, it is important to define the metrics which will be used to compare them. In this context, the proposed solution MSS, with the other two baselines, RMS and MRS are compared in terms of 2 different metrics, which are

- Number of connected SCs when varying each one of the parameters, namely: B, R, and L;

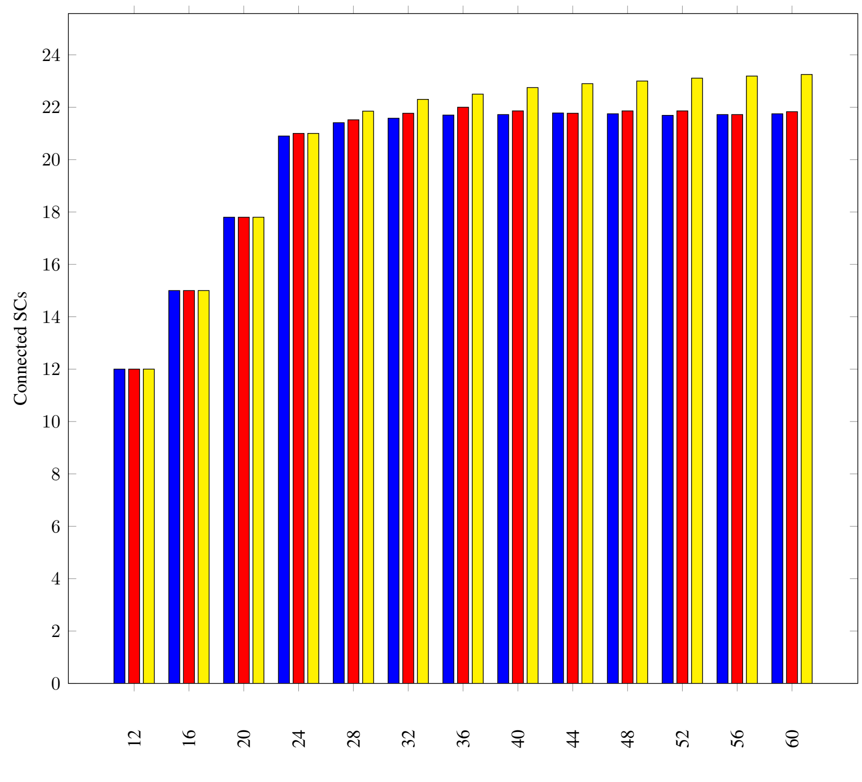

Fig 6: Number of connected SCs for each method, when varying the number of SCs and maximum B.

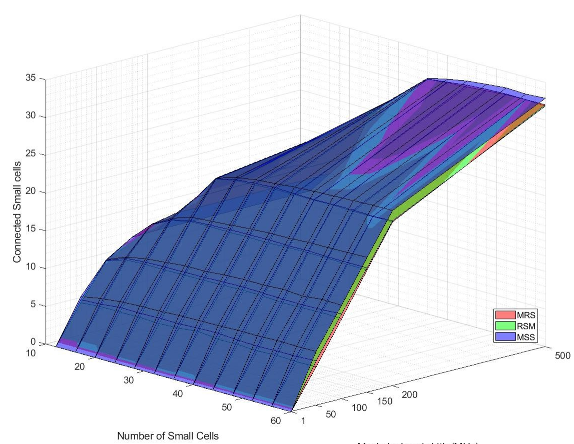

Fig 7: Number of connected SCs for each method, when varying the number of SCs and maximum B.

- Relative gain.

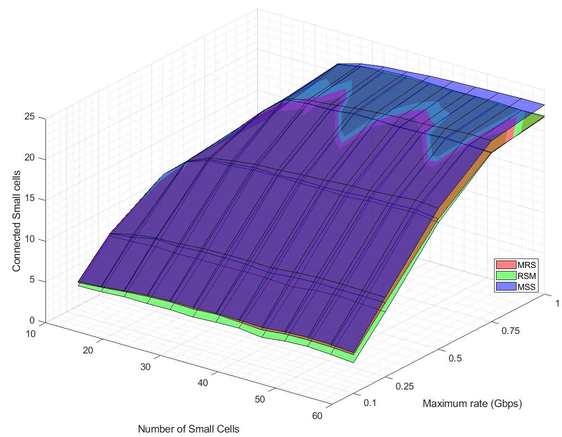

Fig 8: Number of connected SCs for each method, when varying the number of SCs and maximum R.

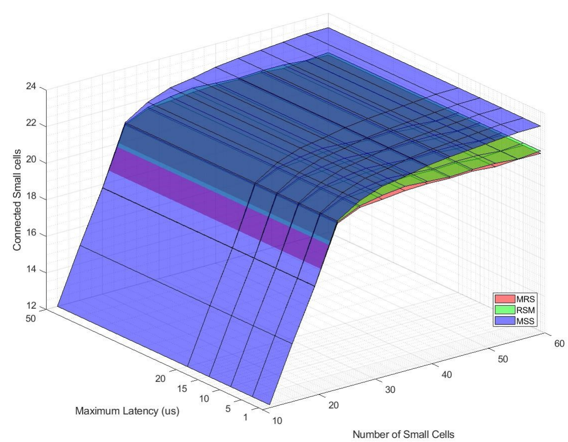

Fig 9: Number of connected SCs for Each method, when varying the number of SCs and the maximum L.

The relative gain is measured only for the proposed MSS solution and is defined as

$$G = 100 \cdot \frac{X_{MSS} - X_{bs}}{X_{MSS}}, \tag{7}$$

where X_{MSS} represents the metric being evaluated for the MSS solution and X_{bs} represents the metric being evaluated for any of the other two baseline methods. Note that if G is negative, it represents a loss, whereas if G is positive it represents a gain.

5.2 Numerical Analysis

Fig. 6 (Number of connected SCs for each method when varying the number of SCs for fixed B, R, L) shows that performance of all three methods is very similar up to 24 SCs. After 24 SCs when the number of SCs increases MSS outperforms the other two methods by 7% and 6.3% when comparing to MRS and RSM. Fig. 7 (Number of connected SCs for each method when varying the number of SCs and maximum B). We can see that the performance of MSS is always better than the other two methods. We can also see that when the maximum B increases, the gap between MSS and MRS and RSM increases, reaching up to 7% and 6.5% gains when compared to MRS and RSM respectively. It can also be seen that bandwidth represents a bottleneck in the system, as when the bandwidth increases up to 500 GHz the number of SCs connected increase up to 33. Fig. 8 (Number of connected SCs for each method, when varying the number of SCs and maximum R). Similar to Fig. 7, the performance of MSS is always superior to MRS and RSM. We can also see that when the number of SCs is below 24, the performance of MSS and MRS are very similar (with MSS outperforming MRS by around 2.3%). When the number of SCs increases past 24, the gap between MSS and the other methods enlarges, reaching gains of 7% and 6.5% respectively. Fig. 9 (Number of connected SCs for each method, when varying the number of SCs and the maximum L). From Fig. 9, it is cleared that when the number of SCs is below 24, the performance of all three methods is very similar with MSS slightly outperforming the other two. When the number of SCs increases past 24, the gap between methods increases, with MSS having gain in the order of 7% and 6.5% when compared to MRS and RSM. For this specific scenario, bandwidth is the bottleneck of the system, since when B is varied, a large gain in terms of the number of SCs connected can be seen. One way of solving this issue can be the deployment of another macro cell, to increase the total fronthaul bandwidth.

6 Conclusions

In this paper, we addressed the problem of fronthaul connection and small cell association in a PON-FSO heterogeneous network scenario. We have proposed solutions considering four network parameters, such as bandwidth, data rate, latency, and a number of fronthaul links. MRS selects cells based on data rate, while RSM considers the SCs randomly i.e. bandwidth, data rate, latency. Based on the simulation results, it is observed that MSS is 7% and 6.5% better performance than RSM and MRS respectively. This approach is vital for the implementation of the SC deployment process in the 5G network.

In the future, we plan to evaluate a more complex network scenario, with more macro cell in a realistic distribution, including other performance parameters such as energy efficiency and a further reduction in latency and cost-saving.

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Syed Saeed Jaffer received his BS degree in electronic engineering from SSUET Karachi in 1999 and M.Sc. in Telecommunication engineering from NWFP-UET Peshawar in 2008. Currently, he is pursuing his Ph.D. in Electrical engineering from HITEC University, Taxila, Pakistan. His research interests are based around future wireless optical 5G networks. He also served for PTCL Pakistan for more than 14 years.

Ashiq Hussain received the B.Sc. degree in Electrical Engineering and M.Sc. Electrical Engineering from UET Taxila in 1999 and 2003 respectively. He Worked as a telecom engineer in Pakistan Telecommunication Company Limited (PTCL) for six years and received M.Sc. Telecommunication Engineering from NWFP-UET Peshawar in 2008. He received the Ph.D. degree in Telecom Engineering from Beijing University of Posts and Telecommunications (BUPT) China in 2011. His areas of interest are optical amplification, radio over fiber, silicon photonics, and optical networks.

Paulo Valente Klaine received the B.Eng. degree in electrical and electronic engineering from the Federal University of Technology–Paraná (UTFPR), Brazil, in 2014, and the M.Sc. degree (Hons.) in mobile communications systems from the University of Surrey, Guildford, U.K., in 2015. He has completed his Ph.D. degree with the School of Engineering, University of Glasgow. In 2016, he spent the first year of his Ph.D. working in the 5G Innovation Centre (5GIC), University of Surrey. His main interests include self-organizing cellular networks and the application of machine learning in cellular networks. Currently he is engaged for his Post Doctorate work at university of Glasgow UK.

Muhammad Zeeshan Shakir is Reader at Artificial Intelligence, Visual Communications and Network (AVCN) research centre, University of the West of Scotland (UWS), UK. With over 10 years of research expertise in design and development of wireless communication systems, he has published over 120 research articles including 40+ peer-reviewed top-tier journal papers; 70+ conference articles, and 10 books. He is a recipient of STARS Award 2018 (Staff Appreciation and Recognition Scheme) for Outstanding Research and Enterprise performance at UWS.

Muhammad Ali Qureshi is working as Assistant Professor in telecommunication engineering department, The Islamia University of Bahawalpur, Pakistan since 2007. He received his B.Sc. degree in electrical engineering from UET Lahore in 2000 and M.Sc. in telecommunication engineering from NWFP-UET Peshawar in 2008. He completed his Ph.D. in electrical engineering from KFUPM, Saudi Arabia in 2017. His research interests include image and video processing, image forensics, image quality assessment, and antenna signal processing. Additionally, he is member of IEEE since 2010, he is a Senior Member of IEEE and Chair IEEE Bahawalpur Subsection Region 10.

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